

Toward a Concept of Operations for Aviation Weather Information Implementation in the Evolving National Airspace System

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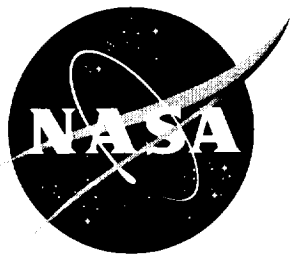
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Acronyms

AFSS	Automated Flight Service Station
AIM	Aeronautical Information Manual
ARTCC	Air Route Traffic control Center
ASIST	Aviation Safety Investment Strategy Team
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
AvSP	Aviation Safety Program
AWIN	Aviation Weather Information
CDM	Collaborative Decision Making
DEMLVAL	Demonstration Validation
DM	Decision Making
EDCT	Expected Departure Clearance Time
EFAS	En-route Flight Advisory Service
FAA	Federal Aviation Administration
FIS	Flight Information Service
FISDL	Flight Information Service Data Link
FSS	Flight Service Station
FW	Flight Watch
IFR	Instrument Flight Rules
ISE	In-flight Service Enhancement
MASPS	Minimum Aviation System Performance Standards
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NWS	National Weather Service
RTCA	Requirements and Technical Concepts for Aviation
SA	Situation Awareness
SUA	Special Use Airspace
SWAP	Severe Weather Avoidance Procedures
TFM	Traffic Flow Management
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
WIN	Weather Information
WINCOMM	Weather Information Communication
WxAP	Weather Accident Prevention

Abstract

The capacity of the National Airspace System is being stressed due to the limits of current technologies. Because of this, the FAA and NASA are working to develop new technologies to increase the system's capacity while enhancing safety. Adverse weather has been determined to be a major factor in aircraft accidents and fatalities and the FAA and NASA have developed programs to improve aviation weather information technologies and communications for system users. The Aviation Weather Information Element of the Weather Accident Prevention Project of NASA's Aviation Safety Program is currently working to develop these technologies in coordination with the FAA and industry. This paper sets forth a theoretical approach to implement these new technologies while addressing the National Airspace System (NAS) as an evolving system with Weather Information as one of its subsystems. With this approach in place, system users will be able to acquire the type of weather information that is needed based upon the type of decision-making situation and condition that is encountered.

The theoretical approach addressed in this paper takes the form of a model for weather information implementation. This model addresses the use of weather information in three decision-making situations, based upon the system user's operational perspective. The model also addresses two decision-making conditions, which are based upon the need for collaboration due to the level of support offered by the weather information provided by each new product or technology. The model is proposed for use in weather information implementation in order to provide a systems approach to the NAS. Enhancements to the NAS collaborative decision-making capabilities are also suggested.

1 INTRODUCTION

The Federal Aviation Administration (FAA) forecasts that air travel will increase substantially over the next couple of decades. Estimates indicate that the number of passengers carried on commercial aircraft will double over the next few years, reaching one billion by 2015. The number of commercial aircraft will increase at an annual rate of 4.0 % (260 aircraft) per year between 2000 and 2010. General aviation and other aircraft operations are also expected to experience a high growth rate. This projected growth in airspace usage will greatly increase the strain on the air transportation system's capacity, safety, and security (source: 2001 FAA National Aviation Research Plan).

In February 1997, the U.S. President announced a national goal to reduce the fatal accident rate for aviation by 80% within ten years. In response to this announcement, the National Aeronautics and Space Administration (NASA) established the Aviation Safety Program (AvSP) to develop technologies needed to meet this aggressive goal. A NASA sponsored Aviation Safety Investment Strategy Team (ASIST) defined the research needs, and identified weather accident prevention as a key area to be addressed.

Because weather has been identified as a causal factor in approximately 30% of all aviation accidents, a Weather Accident Prevention (WxAP) project was established by NASA's Aviation Safety Program. Within this WxAP project, one element was established to address the weather information needs of general, corporate, regional, and transport aircraft operators. This element, the Aviation Weather Information element, is developing the technologies that will provide accurate, timely and intuitive information to pilots, during the en-route phase of flight, to enable the detection and avoidance of aviation weather hazards.

The FAA's program for addressing the national safety goals is called Safer Skies, and this program compliments the NASA effort. The Safer Skies program also includes a hazardous weather avoidance element and features data linking of Flight Information Services (FIS) as a lead technology in mitigating the impact of hazardous weather on flight operations.

1.1. Background

Aviation weather information systems basically consist of weather products, a means of distributing the products to users, and a means of presenting the information. Within NASA's Aviation Safety Program, enhanced weather products and information presentation are being address by an Aviation Weather Information (AWIN) element, and the distribution of the products is being addressed by a Weather Information Communications (WINCOMM) element. The presentation of weather information for airspace users is being specifically addressed by a group of AWIN researchers, of which the author is a member. For NASA's AWIN research, the pilot is the main focus, but other system operators are also considered. Research in the operator support area is centered on enhancing weather situation awareness through the development of advanced weather presentations and decision aids. According to Stough et al. (2000),

Advanced weather presentations will provide information in an intuitive format that is temporally and spatially relevant to the users and their environment. Weather related

decisions will be facilitated through the development of intelligent agents that assist operators in formulating appropriate, safe, and efficient actions in both a strategic and tactical environment.

Operator support [research] will develop adaptive, re-configurable presentations, advanced interface technologies, and decision-making aids coupled with a human-centered systems design approach. This methodology considers the capabilities and limitations of operators and helps to minimize the role of human error as a significant contributing factor in weather related aviation accidents. (p. 7)

The operators (or system users) who use weather information within the National Airspace System (NAS) include pilots, controllers, aviation weather meteorologists, air traffic managers, and weather service providers. Sensed weather data and weather products are transmitted as weather information to a processor at the operator's position. Operator positions range from ground-side positions (such as controller work stations) to cockpit instrument displays. NASA's AWIN element has identified several components of an operator system (see Figure 1-1).

Along with weather information, traffic and navigation information will also be transmitted to the operator's processor where it may be individually selected or integrated for display. Decision aids addressing aircraft and user capabilities are also included in the operator system to aid in the decision-making process. Together, the decision aids, user-system-interface, and information presentation comprise the operator Weather Information (WIN¹) support system. Weather information is exchanged throughout the NAS between its many users operating weather information systems, which may vary within their individual component designs, but which operate according to this basic process.

1.2. Purpose

This paper proposes a theoretical approach for aviation weather information implementation for the evolving NAS. It presents a possible means of meeting the weather information needs of NAS users. A theoretical model is provided for the implementation of developing weather information tools (products and decision aids), based upon each of these tools' attributes and level of support for the decisions to be made. In essence, these products and decision aids are cognitive tools (weather information decision aiding tools), to be used in decision-making processes.

NAS operators make decisions concerning hazardous weather avoidance in three different situations (pre-operational planning, operational planning and operational immediate), while operating autonomously or in collaboration with other NAS operators. These situations will be termed "Decision-Making (DM) Situations." A decision-making situation involves an operator's Situation Awareness (SA) relative to his/her operational status in the NAS. The term "Decision-Making (DM) Conditions" will be used in association with collaborative or autonomous decision-making (see Table 1-1). The purpose of collaboration with weather service providers is to make the best overall/cumulative decisions in hazardous weather avoidance.

¹ The acronym (WIN) will be used in place of "weather information" in tables and figures throughout this paper.

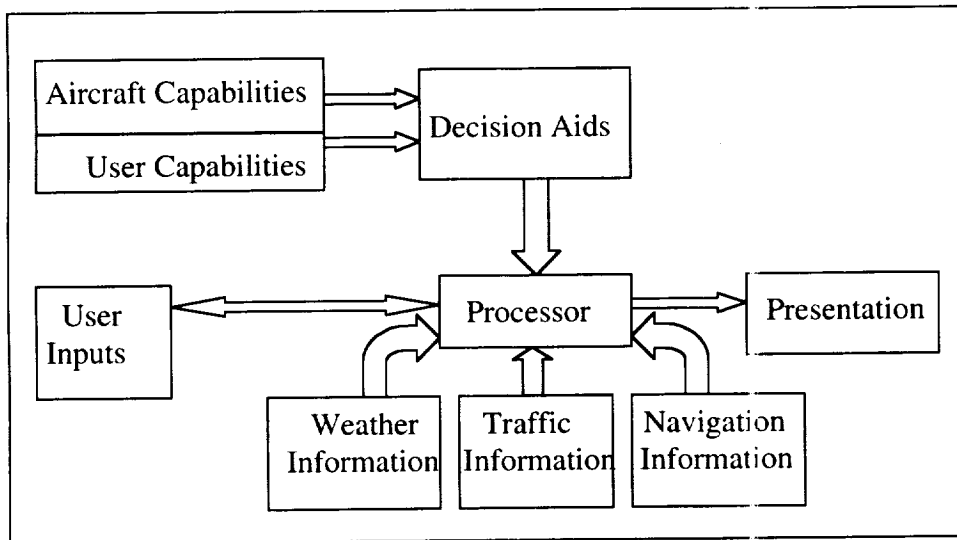


Figure 1-1. Operator Support System Components

This paper will also discuss the FAA's guidance in the usage of cockpit weather displays as tools for enhancing pilots' weather situation awareness when used in conjunction with traditional sources of weather information, rather than as a sole source of information. This paper is not intended to represent any formally approved plans for weather information implementation, nor does it address the human-factors issues concerning approved interface technologies. These issues will be addressed step-by-step as the NAS evolves with advances in technologies.

Table 1-1. NAS WIN Decision-Making (DM) Situations and Conditions

NAS	
Collaborative DM Conditions	Autonomous DM Conditions
1. Pre-Operational Planning DM Situation	1. Pre-Operational Planning DM Situation
2. Operational Planning DM Situation	2. Operational Planning DM Situation
3. Operational Immediate DM Situation	3. Operational Immediate DM Situation

2 A PROPOSED MODEL FOR AVIATION WEATHER INFORMATION IMPLEMENTATION

For aviation weather information to be used effectively for hazardous weather avoidance in collaborative and autonomous DM conditions, a model for aviation weather information implementation addressing the aviation system must be developed. For the world of aviation in the United States, this system is known as the National Airspace System (NAS). To satisfy this requirement, the following description addresses human-factors issues in an attempt to devise a model for the implementation of weather information tools according to a systems approach. Using this type of model, weather information tools would be categorized according to the operational DM situation that they enhance. They would then be evaluated for either collaborative or autonomous DM conditions, and then assigned to an operator position.

In order to ensure that the principles of systems engineering and human factors engineering are appropriately considered, a model for weather-information tool implementation should be established before actually beginning the development of new technologies, however, it may also be used with developing technologies. This model should address the following three premises:

1. Weather information constitutes a subsystem of the NAS, and weather information tools must be developed according to a systems approach for implementation into the NAS.
2. Weather information tools will be used in three different operational DM situations: pre-operational planning DM, operational planning DM and operational immediate DM.
3. Weather information tools are used in two decision-making conditions: collaborative DM conditions and autonomous DM conditions.

In the following sections, the three decision-making situations and the two decision-making conditions will be discussed, and recommendations for the implementation of weather information tools will be presented in the form of a model.

2.1. The NAS Weather Information Subsystem

As a subsystem of the NAS, aviation weather information will be shared throughout the NAS over its evolving weather network architecture. According to the NAS Architecture, Version 4.0 (1999), NAS weather architecture systems are categorized as either “(1) sensors and/or data sources, or (2) processing and display systems” (p. 26-1). The eventual goal of the evolving weather architecture is to have a common source of weather information through a weather sub-network of a NAS-wide information network.

Weather information is used within the NAS by ground-side and airborne system users to aid in decision making for safe, effective and efficient NAS operations. Thus, the weather information subsystem affects most, if not all, other NAS subsystems. Since weather information is used to improve weather situation awareness and to aid in decision making, for the purpose of this paper, weather information is considered to consist of the weather data and products that are transmitted to NAS operators (graphic, textual, and voice). Additionally, decision aids, which use weather data to aid the user in making decisions, will also be considered weather information. Decision aids can range from Intelligent Tailoring Systems that filter information according to phase of flight, and integrate information, to Artificial Intelligent Systems that produce suggested routings or make statistical analyses of the probable success of proposed flights. It is acknowledged that the NASA AWIN element conducts research concerning sensors (and to some extent,

communication links), but these things in themselves are not information or aids to decision making.

The FAA and NASA are collaboratively working to develop enhanced weather products in conjunction with the evolving NAS weather network architecture. As these enhanced products become available to NAS operators, they will provide a potential for improving users' weather situation awareness. The key to ensuring the effective implementation of these enhanced weather products is to develop a model to implement the products appropriately.

2.2. Operational Decision-Making Situations

Operational decision-making situations are psychological in nature, as they address the NAS operator's situational awareness of the weather relative to the NAS situation being encountered. As such, the operational decision-making situations have been developed to illustrate Dr. Mica R. Endsley's model of Situation Awareness (SA) in dynamic decision making, within the context of the NAS-weather information sub-system model. Operational decision-making situations apply to pilots' SA in all categories of aircraft operations (one or two pilots), and to all ground-side NAS operators who are concerned with aircraft operations.

According to Endsley (1995), "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (p. 36). Endsley explains that these three levels of situation awareness (1. perception of elements in current situation, 2. comprehension of current situation, and 3. projection of future status) affect decision making in dynamic systems. Other factors which affect this type of decision-making include: system capability, interface design, stress and workload, complexity, automation, goals and objectives, preconceptions (expectations), information processing mechanisms, long-term memory stores, automaticity, abilities, experiences, and training. When considered together, the levels of SA and the other contributing factors comprise Endsley's model of situation awareness in dynamic decision-making (p. 35).

Viewing Endsley's model within the context of the NAS, an operational decision-making situation is seen as the type of dynamic weather-hazard decision-making situation that the operator is encountering relative to the NAS. Therefore, within a system-wide context, the operational decision-making situation considers the operator's SA from his/her system perspective. By employing Endsley's model to represent the operator's SA within the NAS context, the following three operational decision-making situations can be determined: (1) pre-operational planning, (2) operational planning, and (3) operational immediate. For the NAS operator, the system hazard perspective becomes more critical in this order.

The usage of the terms "pre-operational" and "operational" are based upon the operator's relationship to the NAS when the decision-making occurs. Since the NAS is a dynamic operational system, any decisions, which are made outside of the NAS (prior to system entry), are considered to be pre-operational, and any decisions made within the NAS are considered to be operational. Although pre-operational weather decision-making is not as pressured by multitasking as is operational decision making, it is still considered dynamic decision making because the proposed entry into the NAS is approaching as the decision-making occurs. Also, all

the weather variables being considered during this decision-making effort are known to be in a state of change, or potential change, and these factors are taken into consideration within the operator's SA. Therefore, even though the operator's workload potential is not as pressured by multitasking in this situation, as when operating within the NAS, it is still dynamic. According to Endsley (1995),

Several other aspects of SA should be mentioned at this point. First, although SA has been discussed as a person's knowledge of the environment at a given point in time, it is highly temporal in nature. That is, SA is not necessarily acquired instantaneously but is built up over time. Thus it takes into account the dynamics of the situation that are acquirable only over time and that are used to project the state of the environment in the near future. So although SA consists of an operator's knowledge of the state of the environment at any point in time, this knowledge includes temporal aspects of that environment, relating to both the past and the future. (p. 38)

Therefore, all decision-making efforts using weather information sources are to be considered dynamic in nature. And based upon the previous description, any hazardous weather avoidance decision-making efforts conducted for aircraft operations prior to entering NAS operations (before the pilot calls for clearance [IFR]; before taxi for takeoff begins [VFR]) are considered to be pre-operational decision-making efforts. Likewise, any hazardous weather avoidance decision-making efforts conducted for aircraft operations within the operational NAS (after the pilot calls for clearance [IFR]; after taxi for takeoff begins [VFR]) are considered to be operational decision-making efforts.

2.2.1. The Pre-Operational Planning Decision-Making Situation

A ground-side NAS operator's SA is within the context of this operational decision-making situation while using information to plan for future aircraft operations within the NAS. These plans are made when considering many operational variables, one of which is aviation weather. The plans usually take the form of Expected Departure Clearance Times (EDCT) and/or amended/suggested routings.

A pilot's SA is in a pre-operational planning decision-making situation when he/she is using information to plan an intended flight. Here again, many variables are considered, including aviation weather. For the pilot, these plans take the form of a flight plan.

NAS operators use weather information during pre-flight planning to develop a mental model of aviation weather, which builds comprehension and expectations within their SA. Because the pre-operational planning decision-making situation is generally less pressured by multitasking than the operational planning decision-making situation, NAS operators have more flexibility in their distribution of attention, and more time and attention can be appropriated to weather analysis. It is during this pre-operational planning phase that the basic mental model of weather conditions for NAS operations is developed.

2.2.2. The Operational Planning Decision-Making Situation

A ground-side NAS operator's SA is within the context of this decision-making situation while using information to plan further operations for aircraft currently operating within the NAS,

based upon extrapolations and official forecasts along their intended routes. Again, many variables are considered while making these plans, including weather conditions. The plans usually take the form of amended routings or confirmation of intended routings. The difference here is that the aircraft and the variables being considered are all operating within the NAS at the same time, making planning a multi-tasking effort.

A pilot's SA is in an operational planning decision-making situation while he/she is using information to confirm the current mental model, or to plan amendments to the intended flight plan (based upon changing conditions) after entry into NAS operations. These plans are made in a multi-tasking situation and are based upon many operational variables, including changing weather conditions. Altered plans usually take the form of flight plan amendments.

It is acknowledged that sometimes (especially in two-pilot operations) multitasking can be very limited and the dynamics of the situation may be very uneventful. Even though this can be the case, the potential exists in this operational decision-making situation for high dynamics and a heavy workload. Because of this, it is necessary to view this situation in its potentially critical mode when determining the pilot's weather information needs. This same line of reasoning also applies to ground-side NAS operators.

NAS operators use weather information during in-flight planning to confirm or amend their mental model of aviation weather. This in-flight mental model of aviation weather directs the operator's comprehension and expectations concerning weather SA. Because the operational planning decision-making situation is dynamic, with attention being distributed over many variables, NAS operators must have flexibility in their attention allocation. Very little time (if any) can be appropriated to weather analysis, and plans are based upon available data in its current form and presentation. Because of this, weather information, which would enhance decision making within this operational decision-making situation, would contain attributes such as temporally current and spatially accurate data with valid short-term forecast information (typically called "nowcasted" data). This type of data can be obtained through mechanisms, which trend and/or integrate weather data and provide algorithms for short-term (e.g. 1 to 3 hour) forecasts. Decision-making in this situation would also be greatly enhanced through the introduction of appropriate decision-aiding devices.

2.2.3. The Operational Immediate Decision-Making Situation

Only a pilot's SA can be found within the parameters of this operational decision-making situation. This decision-making situation occurs for the pilot while he/she is using information to directly navigate the aircraft around weather hazards within the current flight environment. For the purpose of providing a conceptual understanding for the reader, the current flight environment may be considered to be the area in which the pilot is actively navigating and making immediate decisions. For weather information (as a subsystem of the NAS), this means the area where the pilot is no longer planning weather avoidance, but is now using weather information to take action to fly around weather hazards.

Pilots use weather information during operational immediate decision making efforts to route the aircraft around weather hazards in the immediate flight environment. Currently, on-board radar is used by the pilot to navigate around a thunderstorm, or through a perceived break in a line of

thunderstorms. On-board radar provides the pilot with directly sensed precipitation data to aid the pilot in deciding where the hazardous weather is in real time. This information greatly enhances the pilot's weather SA and allows for improved immediate decision-making. Because the operational immediate decision-making situation is highly dynamic, with attention being distributed over many variables and decisions being made in real time, pilots must have flexibility in their attention allocation. Data being used to make decisions in this decision-making situation must be considered real-time data (or near real-time, e.g. via telemetry from remote sensors).

2.2.4 Weather Information Situational Applications

Having defined the operational decision-making situations, it is now necessary to describe the application of weather information within these decision-making situations. Weather information (weather data and decision aids) which enhances each of the two more critical decision-making situations should be provided to the NAS operator in a selective format. Because the operational decision-making situation is the type of situation, relative to the NAS, where decision-making must take place, weather information tools (products and decision aids) should be classified according to their ability to enhance decision-making in the more critical dynamic situations.

Any approved weather information tools should be made available to NAS operators for pre-operational planning purposes, but enhanced weather information tools should be made available selectively according to the operational decision-making situation they best enhance. This is particularly true for pilots using Flight Information Service Data Link (FISDL) who need to obtain enhanced weather information tools for use in the operation planning and operational immediate decision-making situations. Enhancements to these decision-making situations should be made available separately at the touch of a button, so that they are not mixed in with other tools, which are not appropriate for the decision-making situation within which the operators SA is working. By having enhanced weather information tools available according to the situation they enhance, the operator is constrained to use the proper information for the situation he/she is in. This is only true, of course, if the operator knows how to make the correct selection (e.g. pre-operational DM weather data, operational planning DM data, or operational immediate DM data). But, learning the use of only three selections is much easier than trying to figure out what data to use from a large store of information.

In accordance with this procedure, weather information tools should be classified as described in Table 2-1. Approved weather products are those products that have been evaluated and approved for NAS operator usage by the FAA Aviation Weather Directorate. Decision Aids contain, but are not limited to, features such as Intelligent Information Management, Warning and Alerting, Aiding in Training, Aiding in Collaborative Decision-Making (CDM), and Management of the weather information system. Nowcasted aviation weather products are products derived through weather trending, product integration, growth/decay detection, short-term forecast projection, and other techniques. These products contain certain attributes which establish a valid graphic depiction of where the weather hazard is most likely located in real time, and where it most probably will be located in the near future (e.g. 1 to 3 hours). Nowcasted Weather Products enhance operators' weather situation awareness with graphically depicted weather hazards that are easily interpreted at a glance. Directly-sensed data may be obtained from on-board sensors, or through telemetry from remote sensors.

Based upon this weather-information tool classification system and the premise that weather information is a subsystem of the NAS, the operational decision-making situations take shape (see Table 2-2). Any approved weather information products and decision aids can be used by ground-side or aircraft operators in the pre-operational planning decision-making situation prior to entry into the NAS, or before becoming operational, where multitasking pressures are greatly increased. Weather products and decision aids, which are determined to be enhancements

Table 2-1. WIN Classification by Operational Decision-Making Situation

Pre-operational Planning Decision-Making Situation	} Any Approved Aviation Weather Products/Decision Aids
Operational Planning Decision-Making Situation	} Nowcasted Aviation Weather Products and Decision-Aiding Products/Devices
Operational Immediate Decision-Making Situation	} Directly-Sensed Weather Data (Real-Time/Near Real Time)

to decision-making during operational planning, may be classified as tools for aiding the operational-planning decision-making situation. These products and decision aids should be available to the user separately from other weather information tools, so that they may be easily obtained and not confused with products that are not normally appropriate for use in a dynamic, operational, multitasking situation. Directly-sensed weather data and other near real-time data obtained through telemetry are considered aids to the operational immediate decision-making situation and should also be made separately available for direct navigation around weather hazards.

2.3. Decision-Making Conditions

The third premise states that weather information is used within the NAS in two decision-making conditions. These decision-making conditions are either collaborative or autonomous (non-collaborative), based upon the level of support that the information provides to the pilot, as well as his/her need to collaborate. The level of support is based upon the accuracy of the information (spatially and temporally) within the operational decision-making situation in which its use is being considered, and this in turn has a direct influence on the operator's need to collaborate. Collaboration is conducted for the purpose of accomplishing NAS operations efficiently, effectively and safely through the use of multiple resources. Collaborative efforts should entail a sharing of information and expertise between the appropriate NAS operators for the task at hand.

Ideally, collaborative decision-making concerning weather only applies to planning activities. Therefore, collaboration should only occur within the pre-operational planning and operational planning decision-making situations. It is only reasonable to say that a pilot in an operational immediate decision-making situation, using weather information as an aid to navigate around or

Table 2-2. WIN Operational Decision-Making Situations/Tools

<p><u>Pre-operational Planning Decision-Making Situation</u></p> <p><u>Occurs during Pre-operations prior to entering the NAS</u></p> <table> <tr> <td> <p><u>Ground-Side Users</u></p> <p>Planning for future aircraft operations</p> </td><td> <p><u>Aircraft Operators</u></p> <p>Pre-Flight Planning Situations</p> </td></tr> </table> <p><u>WIN Tools</u></p> <p>Any approved weather products/aids</p>		<p><u>Ground-Side Users</u></p> <p>Planning for future aircraft operations</p>	<p><u>Aircraft Operators</u></p> <p>Pre-Flight Planning Situations</p>
<p><u>Ground-Side Users</u></p> <p>Planning for future aircraft operations</p>	<p><u>Aircraft Operators</u></p> <p>Pre-Flight Planning Situations</p>		
<p><u>Operational Planning Decision-Making Situation</u></p> <p><u>Planning which occurs during dynamic NAS operations</u></p> <table> <tr> <td> <p><u>Ground-Side Users</u></p> <p>Planning for aircraft currently operating in the NAS</p> </td><td> <p><u>Aircraft Operators</u></p> <p>En-Route Planning Situations</p> </td></tr> </table> <p><u>WIN Tools (Available Selectively)</u></p> <ol style="list-style-type: none"> 1. Weather products/aids specifically designed to enhance Operational Planning And 2. Any other approved weather products/aids 		<p><u>Ground-Side Users</u></p> <p>Planning for aircraft currently operating in the NAS</p>	<p><u>Aircraft Operators</u></p> <p>En-Route Planning Situations</p>
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through breaks in weather hazards in real time, is under too great a workload to depend upon collaboration. The pilot would only attempt collaboration at this time if the information/data being used were insufficient for the task. Attempts at collaboration under these conditions would be a call for help in an urgent situation. This type of urgent situation should only occur as a result of insufficient planning.

2.3.1. Collaborative Decision-Making (CDM) Conditions

Collaborative Decision Making related to weather should occur within three environments: (1) between ground-side NAS operators for pre-operational planning and operational planning purposes, (2) between pilots and weather service providers during pre-flight for pre-operational planning purposes, and (3) between airborne pilots and weather service providers for en-route operational planning purposes.

2.3.1.1. Ground-side Operator—Ground-side Operator CDM

Ground-side NAS operators collaborate with one another to make pre-operational planning decisions for future aircraft operations before the aircraft enter active NAS operations, and to make operational planning decisions for aircraft currently operating within the NAS. Since ground-side operators coordinate activities for traffic management purposes, pre-operational planning and operational planning efforts usually affect one another and are, therefore, conducted simultaneously. Ground-side collaboration concerning weather occurs between airline dispatchers, meteorologists, ATC weather service units, the FAA's Air Traffic Control System Command Center (ATCSCC), Air Route Traffic Control Center (ARTCC) Traffic Management Units (TMU), and Terminal Radar Approach Controls (TRACON). One tool that is currently in use by these operators is the Collaborative Convective Forecast Product. This tool allows ground-side operators to review forecasts over the Internet several times a day and to update aircraft routes based on real-time information. This type of collaboration also results in expected departure clearance times based upon traffic management activities for aircraft proposing to enter the NAS.

2.3.1.2. Pre-flight Pilot—Weather Service Provider CDM

During pre-flight planning, pilots collaborate with weather service providers, such as Flight Service Specialists and Airline Operations Specialists, to plan hazardous weather avoidance tactics for the proposed flight. This type of planning usually takes place over the telephone, or at the counter in the Flight Service Station (FSS) or at Airline Operations. This effort usually results with the pilot filing a flight plan.

2.3.1.3. En-route Pilot—Weather Service Provider CDM

Once en-route, pilots collaborate with weather service providers by radio to update their pre-flight weather information and to plan for hazardous weather avoidance tactics for conditions, which have changed since their pre-flight weather briefing. FSS in-flight specialists and operations specialists provide weather updates and suggested re-routings, and Flight Watch (FW) specialists provide En-route Flight Advisory Service (EFAS).

EFAS is a specialized type of weather briefing service designed to enhance safety for en-route aircraft. The FW specialist is trained to trend, and analyze weather conditions in his/her area of responsibility in order to provide the most current route-specific weather information available to en-route aircraft. The weather analysis conducted by the FW specialist is sometimes called "nowcasting." FW specialists also make suggestions concerning re-routings and alternate airports, but unlike the FSS In-flight Specialists, who are very busy providing other in-flight services (e.g. filing and opening/closing flight plans), providing EFAS is their only activity.

2.3.2. Autonomous Decision-Making Conditions

As mentioned earlier, the need to collaborate for hazardous weather avoidance is primarily a factor of the level of support provided by the weather information available to the operator. This is especially true for airborne pilots using FISDL. If the level of support were to be improved greatly, the need to collaborate with weather service providers may decrease proportionally. For pilots, the most advanced technologies would be autonomous decision-making operator support tools. Once these tools are developed, the ability of the pilot to go-it-alone will be enhanced, and the time or need to collaborate will be decreased.

Regardless of how much technology improves, however, collaboration between ground-side operators will almost certainly continue to be necessary well into the future because these operators must coordinate NAS activities based upon the influence of many interdependent variables, of which weather information is just one consideration. Weather service providers will also continue to need tools for collaboration because it is their purpose to provide necessary information to pilots. Ideally, these operators should be provided with at least the same tools that are provided to pilots over FISDL so that they may collaborate over common data. Because of these considerations, once enhanced weather products and decision aids are advanced enough to be targeted for autonomous decision-making conditions, they will primarily be considered for use by pilots.

2.4. A Model for Weather Information Tool Implementation

Now that the three premises concerning weather information have been defined and discussed, it is time to elaborate on how weather information tools can be implemented through the use of a model that addresses these premises. In order to accomplish this task, it will be necessary to address each of the premises within the model when considering potential decision-aiding tools, such as weather products and decisions aids (Figure 2-1).

The first premise is addressed within the design of the model in that it includes the decision-making situations and conditions, which are associated with the NAS (the overall system). Therefore, any weather information tool assigned to an operational position in accordance with this model would be considered a part of the weather information subsystem of the NAS.

The second premise is addressed in the model by assigning weather information tools for NAS implementation according to how their attributes support the different decision-making situations. Tools are assigned to the most critical DM situation that their attributes enhance.

2.4.1. Pre-Operational Planning DM—Weather Information Tools

According to this model, weather products and decision aids targeted for the weather information subsystem would first be assigned a classification based upon their attributes. Since the FAA Aviation Weather Directorate approves weather products for use by NAS operators, it is the jurisdiction of this office to qualify products for general use within the weather information subsystem. Therefore, any weather products approved by this office contain the appropriate attributes and meet the requirements to be used for pre-operational planning decision-making situations. These products may be used for pre-operational planning by ground-side operators, as well as pilots. Any decision aids, which use approved weather data, would also be appropriate for use in this type of planning situation. However, products that have not been found to contain

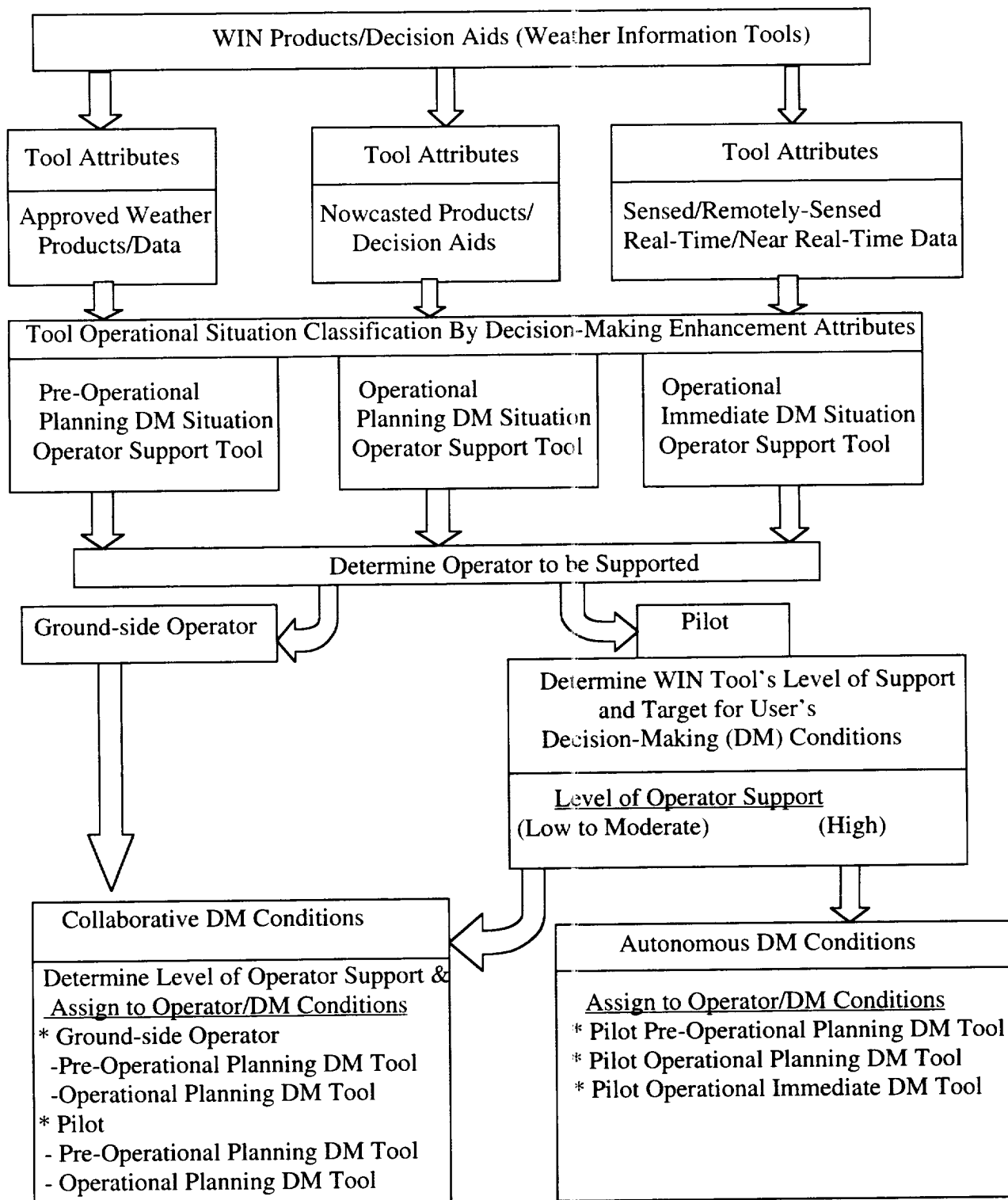


Figure 2-1. Model for WIN Implementation

the appropriate attributes to be used for operational planning or immediate decision making probably should not be used in conjunction with own-ship position icons in cockpit FISDL displays. Pilots may become confused by spatial-temporal inconsistencies, unless training on the use of these products in the cockpit is provided.

2.4.2. Operational Planning DM—Weather Information Tools

In order to meet the necessary criteria for use in an operational planning decision-making situation, approved weather products must possess the necessary attributes required to enhance decision-making in a dynamic, operational, multitasking situation. At a minimum, these products should contain hazard data, which meet approved spatial and temporal guidelines for use by NAS operators. These products should also contain a forecast depiction of one to three hours illustrating where the weather hazard is expected to be, with an accuracy that is at least as good as current weather forecasts from the National Weather Service (NWS). Integrated products should also depict this type of short-term forecast. This information could be depicted in a graphic format overlaying a map, which superimposes aircraft-position icons, so that it can be interpreted easily by the user at a glance. For pilots, this icon should represent own-ship position. For ground-side operators, these icons should represent the positions of relevant aircraft actively operating within the NAS. Since weather decision aids are only as good as the information they use to interpret weather conditions, they must use all relevant current information along the intended route of the aircraft, in order to be considered for use as operational planning decision aids. Decision aids must also demonstrate a high degree of validity in any of their recommendations.

2.4.3. Operational Immediate DM—Weather Information Tools

In order to meet the necessary criteria for use in operational immediate decision-making situations, approved weather products must possess the necessary attributes required to enhance decision-making in a dynamic, operational, multitasking, real-time situation. These data or products must meet the approved spatial guidelines for use by NAS operators, and they must be temporally real-time, or near real-time. In order to be considered for use in this decision-making situation, a near real-time weather information tool must be considered representational of current conditions upon receipt, with very little aging before being updated. This data should also be depicted in a graphic format on a map display, which indicates the aircraft own-ship position in relation to the weather hazard.

2.4.4. Decision-Making Conditions—Weather Information Tool Support

Classification of weather products and decision aids as tools for collaborative or autonomous decision-making conditions is based upon the level of support that the tool provides to the operator. Weather Information tools that only meet the basic requirements for pre-operational planning (acceptance by the FAA Weather Directorate for use in the NAS) provide a low level of support. Weather information tools that only meet the basic requirements for operational planning (nowcasted products with current NWS forecasting accuracy, and decision aids, which use all available weather data and provide highly valid recommendations) provide a moderate level of support. Finally, weather information tools that provide directly sensed, real-time, or near-real-time data from onboard or remote sensors in a high-fidelity presentation, and nowcasted products, with greatly-enhanced (e.g. 90%) forecasting accuracy, provide a high level of support.

3. WHAT'S MISSING IN THE NAS COLLABORATIVE DECISION-MAKING PLANS?

Now that a theoretical model that addresses weather information implementation for the NAS has been described, it is time to compare this model's assumptions toward collaborative decision-making with those in the FAA's plans. Any discrepancy between the FAA's plans to meet the assumptions specified in the model may, theoretically, be attributed to a failure in the FAA's plan to address all the issues involved in a systems approach to the NAS.

The Federal Aviation Administration's (FAA) National Airspace System Architecture, Version 4.0 (1999) calls for collaborative decision making between air traffic control (ATC) service providers/pilots, ATC service providers/Traffic Flow Management (TFM) service providers, TFM service providers/flight planners, and pilots/flight planners. The collaborative process will use a common data source to share information. Data types include: flight data, resource data, enhanced weather data, traffic management data, NAS performance measurement data, geographic data, and surveillance data (p. 19-7). The NAS architecture plans describe how new weather products and technologies, such as Flight Information Service (FIS) data-linked weather, will be used in collaborative efforts to avoid hazardous weather conditions.

Integrated weather products will be uplinked to the cockpit, initially by FIS to assist pilots in avoiding hazardous weather. An improved and shared view of weather information among aircrews, controllers, dispatchers, and meteorologists enhances weather communications by increasing understanding of weather and permitting collaborative replanning of flights. (p. 7-5)

The NAS Architecture 4.0 also states that the FAA's Safe Flight 21 program will help to determine what the controllers' responsibilities are, concerning severe weather separation and collaborative decision making.

Safe Flight 21 demonstration validations (DEMVALS) for FIS and weather services will involve specific operational improvements for different aircraft types operating at various altitudes under IFR and VFR flight plans. The DEMVALS will also include the impact of FIS/weather data link on air traffic control procedures, pilot-controller responsibility for severe weather separation, and collaborative decision-making. (p. 25-2)

A better approach to defining the roles of NAS operators in the collaborative decision-making process would be to address the responsibilities of the appropriate service providers and their roles in providing weather services. Enhanced weather data (or aviation weather data in general) are provided to en-route aircraft by weather service providers (Dispatchers, Automated Flight Service Station [AFSS] Specialists and Flight Watch [FW] Specialists). Air traffic controllers need to have weather data to aid in developing traffic separation and routing strategies, but it is not their responsibility to collaborate with pilots over hazardous weather avoidance procedures. Additionally, controllers are not qualified or certified to provide hazardous weather avoidance information to pilots, nor do they normally have the time to provide it. They are simply too busy separating aircraft. However, it is accepted that controllers will aid pilots using the weather

information that they have at hand in urgent situations, when a pilot requests immediate help in avoiding weather hazards.

In normal NAS operations, aviators obtain en-route weather aid from weather service providers. Dispatchers, AFSS Specialists, and Flight Watch Specialists are trained and certified by the National Weather Service to provide in-flight weather services to en-route aviators. Additionally, it is the job of Flight Watch Specialists to trend, analyze and “nowcast” weather data so that they may provide En-route Flight Advisory Service (EFAS). This service is specifically designed to enhance aviation safety by aiding all categories of aircraft operating in the NAS, both IFR and VFR, in re-routing to avoid hazardous weather conditions. FAA Order 7110.51D covers the subject of EFAS, and Order 7110.10N Flight Services, covers the EFAS operating procedures. The 7110.10N states the procedure used by FW in providing EFAS:

Tailor en-route flight advisories to the phase of flight that begins after climb out and ends with descent to land. Current weather and terminal forecast at the airport of first intended landing and/or the alternate airport shall be provided on request. When conditions dictate, provide information on weather for alternate routes and/or altitudes to assist the pilot in the avoidance of hazardous flight conditions. Advise the pilot to contact the adjacent flight watch facility when adverse weather conditions along the intended route extend beyond the FWA [Flight Watch Area]. (p. 4-6-1)

In the near future, pilots will be obtaining more and more enhanced weather data through Flight Information Service Data Link (FISDL). They will also become more self-reliant in obtaining pre-flight briefing data independently. As this occurs, the role of the AFSS specialists will change. The NAS Architecture, Version 4.0 states that future AFSS weather services will become more focussed on in-flight weather support. “As pilots become more self-reliant and depend less on direct contact, in-flight services (e.g., in-flight weather support, VFR flight following, and search and rescue support) will ultimately become the principal focus of the flight service specialist” (p. 25-2).

Because of this future in-flight weather support focus, it is clear that AFSS in-flight services, in general, and Flight Watch EFAS services in particular, should be enhanced with advanced weather data and equipment. Enhancements will be necessary to improve the specialists’ capability of providing FIS-equipped aircraft with appropriate weather support and to enhance the specialists’ ability to collaborate with pilots effectively. These service providers should be provided with at least the same enhanced weather products that will be provided over FIS data link, and with an aircraft situation display which superimposes weather data over a map, characteristically similar to the display to be provided to controllers. These improvements would serve to greatly enhance the situation awareness of the weather-service-providing specialist and his/her capability to provide necessary weather services.

As aircraft become equipped with FISDL, it will be imperative that pilots become trained in its usage as an aid to collaborative decision making. The Aeronautical Information Manual (AIM) states that FISDL does not serve as a sole source of aeronautical weather and operational information, and that FISDL supports strategic weather decision making for route selection to avoid a weather hazard area in its entirety. The AIM also describes how FISDL is best used.

FISDL supports better pilot decision making by increasing situational awareness. The best decision making is based on using information from a variety of sources. In addition to FISDL, pilots should take advantage of other weather/NAS status sources, including, but not limited to, Flight Service Stations, Flight Watch, other air traffic control facilities, airline operation control centers, pilot reports, and their own personal observations. (p. 7-1-10)

The Minimum Aviation System Performance Standards (MASPS) for Flight Information Services—Broadcast (FIS—B) Data Link, prepared by Special Committee 195 of the Requirements and Technical Concepts for Aviation (RTCA) organization also addresses the use of FISDL.

Implementation of an FIS—B data link system is not intended to replace existing voice radio FIS services or preflight briefing. Loss or non-receipt of FIS—B data link services (DLS) would not be considered flight critical. In the initial implementation, it is anticipated that FIS—B DLS will be used primarily to supplement or complement established sources of weather and operational information such as the Flight Service Station network, the Air Traffic Control (ATC) facilities, and/or the corporate/airline dispatchers. FIS—B services will assist both individual pilot and collaborative decision making (CDM) processes. (p. 3, 1.3)

4 SUMMARY AND CONCLUSIONS

The FAA's plans for the architecture of the National Airspace System call for an evolving communication system, which will eventually lead to a common source of weather data to be shared by all NAS operators. The weather information subsystem of the NAS is currently evolving along with the NAS architecture as new products and technologies are developed. In order to effectively implement these new technologies into the NAS, a model that addresses the premises associated with the weather information subsystem should be developed.

The first premise associated with weather information is that it is a subsystem of the NAS, and weather information tools must be developed according to a systems approach to the NAS. This means that weather information tool implementation must consider all aspects of the NAS environment where weather information is to be used. This is especially true where collaborative decision-making conditions occur. Weather information tool users must collaborate with the appropriate NAS operators, and those operators must be provided with the necessary weather service capability to provide the service that they must deliver. For the weather information subsystem, pilots should collaborate with weather service providers, and ground-side operators should share information with all pertinent operational positions. Weather service providers must be provided with (1) the same weather information enhancements that are provided to FISDL services in order to ensure the use of common data during collaboration efforts, and (2) an aircraft situation display, which superimposes weather information over a map to increase the operator's SA. The latter is particularly necessary for FW to enhance its EFAS capability.

The second premise concerning NAS weather information is that decision-making using weather information tools takes place in three types of situations relative to the NAS. These situations are known as operational decision-making situations, and they represent the operator's SA in dynamic decision-making, based upon the operator's system weather-hazard perspective. The Pre-Operational Planning Decision-Making Situation occurs for operators considering operations for aircraft prior to their entry into the operational NAS. The Operational Planning Decision-Making Situation occurs for operators considering continuing operations for aircraft after their entry into NAS operations. The Operational Immediate Decision-Making Situation occurs for pilots during immediate navigation around weather hazards.

The third premise concerning NAS weather information is that weather information tools are used within the NAS under two decision-making conditions. These decision-making conditions are either collaborative, or autonomous, based upon the level of support that the weather information tools provide, as well as the user's need to collaborate. The level of support is based upon the accuracy of the information (spatially and temporally) within the operational decision-making situation in which its use is being considered, and this in turn has a direct influence on the operator's need to collaborate.

Since ground-side operators must coordinate over several variables (of which weather is only one) while conducting traffic management activities, collaborative decision-making conditions will most likely continue to exist for these operators far into the future, even with the introduction of advanced weather information technologies possessing high levels of support.

Likewise, ground-side weather service providers will continue to collaborate with pilots as long as pilots have a need to collaborate. Because of this, autonomous decision-making weather tools will be developed primarily for pilots. The need for pilots to collaborate with weather service providers over hazardous weather avoidance planning will continue to exist until weather information tools are advance enough to provide the pilot with the capability to go-it-alone in autonomous, pre-operational planning and operational-planning decision-making situations. In order for this to occur, weather information tools, which exhibit high fidelity presentations with extremely accurate algorithms, will need to be developed.

Because FISDL is intended to support established weather sources and the collaborative decision-making process, it is clear that, in addition to operational enhancements, the NAS Architecture model for collaborative decision making should be amended to include weather service providers in both ground-side and air/ground weather collaboration. Ground-side collaborative decision making currently includes Airline Operation Centers, ATCSCC, ARTCC (TMU), and TRACON facilities. Ground-side collaborative decisions concerning re-routings of IFR aircraft for hazardous weather avoidance are currently made without sharing this information with AFSS/EFAS specialists. Because of this deficiency, IFR pilots sometimes contact the AFSS or Flight Watch to obtain suggestions for hazardous weather avoidance routings, and obtain suggestions that do not coincide with the routings being used by the ground-side collaborators. This sometimes leads to conflict between controllers and AFSS In-flight/FW specialists. To correct this deficiency, it would be beneficial for the ground-side collaborative decision-making model to include a link between the ARTCC Traffic Management Unit (TMU) and its associated Flight Watch Unit. There should then be an additional link created between Flight Watch and the AFSS In-flight positions located within the Flight Watch Area. This way, weather service providers will know how IFR traffic within their respective areas of responsibility is being managed by ATC during hazardous weather avoidance procedures (e.g. the ARTCC's Strategic Weather Avoidance Procedures [SWAP]).

5 RECOMMENDATIONS

Weather Information Tool Classification by Decision-Making Situation

It is recommended that weather information tools (products and decision aids) be classified by the most critical operational decision-making situation that they enhance, according to their attributes. They should then be made available to operators selectively by the decision-making situation they enhance, so that operators may select the appropriate products and decision aids for the situation they are experiencing (pre-operational planning decision making, operational planning decision making, or operational immediate decision making). For example, a pilot using FISDL should be able to select a category of weather information tools on his/her display, which enhances operational (en-route) planning decision making without having other weather products mixed in with them. These tools would include “nowcasted” products and appropriate decision aids. The use of these tools en-route would provide the pilot with spatially/temporally pertinent, route-relevant weather information without significantly increasing the pilot’s workload. The same benefits would also apply to other NAS operators in other situations using the appropriate type of weather information tools for decision aiding.

Targeting Weather Information Tools For Decision-Making Conditions

It is also recommended that weather information planning tools, which provide the user with a low-to-moderate level of support in decision making, be targeted for collaborative decision-making conditions in a systematic manner, which ensures that collaborators are provided with common data. All weather information tools targeted for collaborative decision-making conditions will be for planning purposes only (pre-operational planning and operational planning). This is because a low-moderate level of support is not enough to eliminate the need for collaboration, and it is not enough to allow a pilot to make immediate decisions concerning hazardous weather in the current flight environment.

Operational immediate decision making conditions need the aid of weather information tools, which provide a high level of support so that the pilot may operate autonomously. Weather information tools used for operational immediate decision making should exhibit high fidelity presentations of weather hazards with their positions easily interpreted relative to the aircraft. Parallel research and development efforts should continue toward the development of weather information tools that support all decision-making situations in both collaborative and autonomous decision-making conditions, and these tools should be made available to operators upon their certification and/or approval for use in the NAS.

Ground-side Collaborative Decision-making Model Amendment

In order to ensure the proper sharing of information, it is recommended that NAS architecture models describing ground-side collaboration be upgraded to include a link between the ARTCC TMU and the AFSS FW for the sharing of information concerning procedures for IFR hazardous weather avoidance. An additional link should be provided between the FW and the other AFSS facilities in the FWA. The TMU should keep the FW informed of any SWAP procedures that are in effect, so that conflicting recommendations do not occur when IFR aircraft contact FW for EFAS, or contact the AFSS for weather updates and recommendations.

Air-Ground Collaborative Decision-making Model

In addition to ground-side collaboration, the NAS architecture plans for Pilot-Controller collaborative decision making concerning hazardous weather avoidance should be clarified to describe Pilot-Weather Service Provider collaborative decision making. Controllers are not certified or qualified to provide weather services and they don't usually have the time to provide this service. Controllers will aid pilots in urgent situations to avoid hazardous weather, if possible, but it is the job of weather service providers, particularly Flight Watch with its En-route Flight Advisory Service, to provide the most current and timely weather conditions to en-route aircraft. Weather service providers (particularly Flight Watch) should receive the same weather information enhancements that will be available to pilots and controllers.

Flight Watch Equipment Enhancement

It would also be very beneficial to Flight Watch to have an aircraft position display superimposing weather radar and/or enhanced weather products over the FWA map. Such a display, known as the Special Use Airspace/In-flight Service Enhancement (SUA/ISE) has been developed and tested at FTW AFSS. There were initial problems with the Special Use Airspace portion of the system, but the In-flight Service Enhancement has demonstrated the improved effectiveness of EFAS service made possible by the aircraft situation/weather radar display. With this display, the FW specialist is given an improved situation awareness of the aircraft and its relation to hazardous weather, and more effective recommendations are made possible. Since the FW specialist has the job of trending and analyzing the weather conditions in his/her area of responsibility, better collaborative decision making can be made possible with FIS-equipped aircraft in the future, if this display (or a similar one) is made available to Flight Watch. If pilots are made aware of an improved capability of weather service providers, particularly like the one described above for FW, they will be more inclined to use the FIS weather display as it is intended (as an aid to collaborative decision-making).

Pilots would also be more inclined to call FW if more than one low-altitude frequency was made available. Frequency congestion is also a problem in obtaining EFAS. One of the discrete AFSS frequencies could be changed to a FW frequency so that FW can have more than the one low-altitude frequency, which is universal to all FW stations (122.0 MHz). AFSSs also have a universal frequency (122.2 MHz), and usually two or three discrete frequencies. Flight Watch has a larger area of coverage than the AFSS and this requires additional frequencies to avoid the problem of frequency congestion, which plagues EFAS service providers during busy periods.

Collaborative Decision-making Training

Pilot and Weather Service Provider training in collaborative decision making would also improve the collaborative process. FIS is intended to provide weather information to be used as a strategic aid in conjunction with services provided by weather service providers. It has been demonstrated (Yuchnovicz et al., August 2001) that pilots, using basic FIS weather displays (with no aircraft situation display, nowcasted products or decision aids), without the aid of other weather information sources, tended to make poor weather avoidance decisions. These pilots made even poorer decisions than pilots who had no FIS display. It has also been demonstrated (Novacek, et al., December 2001) that the addition of own-ship position on a cockpit weather information display did not significantly improve pilot decision making, although the pilots exhibited improved situation awareness and decreased workload.

Because collaborative decision-making between pilots and weather service providers will continue for some time, it is recommended that both pilots and weather service providers obtain training in the use of new weather decision-aiding tools and in the collaborative decision-making process. Pilots should know which NAS operators to contact for weather support and the capabilities of each. They should also know what information the weather service provider needs from the pilot on initial contact (e.g. type aircraft, position, altitude, IFR or VFR, FISDL capability, available weather information, intentions, etc.). Likewise, weather service providers need to know what the weather information capabilities are for different FISDL systems. Pilots also need to know what errors and potentially hazardous situations can occur through the inappropriate use of cockpit weather information systems.

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13. ABSTRACT (Maximum 200 words) The capacity of the National Airspace System is being stressed due to the limits of current technologies. Because of this, the FAA and NASA are working to develop new technologies to increase the system's capacity while enhancing safety. Adverse weather is a major factor in aircraft accidents and fatalities and the FAA and NASA have developed programs to improve aviation weather information technologies and communications for system users. The AWIN Element of the NASA Aviation Safety Program is currently working to develop these technologies in coordination with the FAA and industry. This paper describes a theoretical approach to implement new technologies while addressing the National Airspace System (NAS) as an evolving system with Weather Information as one of its subsystems, so that system users may acquire the type of weather information they need based upon the system perspective encountered. This theoretical approach takes the form of a model for weather information implementation. It addresses the use of weather information in three decision-making situations, based upon the system user's perspective. The model also addresses two decision-making conditions, based upon the need for collaboration due to the level of support provided by each product or technology. The model for weather implementation is proposed for use to provide a systems approach to the NAS, and enhancements to the collaborative decision-making process are suggested.				
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